Vegetation Management

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EFFICACY OF DORMANT SEASON BASAL APPLICATIONS OF IMAZAPYR AND TRICLOPYR FOR CONTROLLING UNDESIRABLE WOODY STEMS

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Abstract-A total of **23** herbicide treatments were applied under the auspices of 3 separate projects to evaluate the efficacy of basal applications utilizing imazapyr and/or triclopyr on selected species. Seven species were treated at the study locations in Mississippi and six species were treated at study sites in South Carolina. Results indicated that imazapyr was effective as a basal treatment with the addition of triclopyr improving control on many species. The addition of Weedone 170 did not significantly improve control of species in this study. Increasing the rate of imazapyr or triclopyr did not consistently improve control, but the basal applications of these herbicides controlled species considered to be resistant to foliar applications of imazapyr.

INTRODUCTION

Timber stand improvement activities have been an integral component of forest management for decades. While the most common form of individual stem treatment used in forestry has been injection, the application of herbicides in basal sprays has been practiced for nearly 40 years. Basal applications have been used extensively for many years in right-of-way management, and forest managers have used the technique sparingly for a number of possible reasons.

Until 1979, (Clason 1991, Hendler and others 1987) 5-T was the principal herbicide used in basal applications. Since that time, triclopyr has been tested and the ester formulation has given excellent control of a number of species (Hendler and others 1987, Miller and Glover 1993, Warren 1982, Yeiser and others 1989). The primary focus of these studies has been on using basal applications for pine release, but Clason (1991) evaluated the use of this methodology for precommercial thinning of pines.

Studies evaluating the use of triclopyr as a "streamline" application (Burch and others 1987, Schutzman and Kidd 1987, Yeiser and Boyd 1989) demonstrated efficacies of different equipment and timing in basal applications. Later work explored the importance of different carriers in basal work (9).

Tank-mixing triclopyr with picloram has been shown to give excellent control (Hall and Hendler 1986). Also, imazapyr and triclopyr had been evaluated as streamline applications separately, but not as tank mixtures in one earlier study (Pancake and Miller 1990). Given that imazapyr and triclopyr were both effective in basal application for woody stem control, the purpose of this study was to evaluate combinations Chopper EC® and Garlon 4® on a variety of tree species.

MATERIALS AND METHODS

The overall study included the protocols for three separate projects which shall be referred to as Projects "A," "B," and "C." All three projects shared some protocols in that treated stems should be 1 to 4 inches (in.) diameter at breast height (d.b.h.), the lower 12 to 18 in. of stem would be treated, each stem would be flagged and tagged for identification purposes, applications were made during the dormant season, and all stems were evaluated at the end of the first and second growing seasons following application. For each treated stem, the herbicide mixture was applied until the bark was moistened, with care taken not to apply excessive amounts which would cause puddling at the root collar. Approximately 30 milliliters (ml) of solution were used per treated stem in the study, with Penevator Basal Oil used as the carrier.

The objective of Project "A" was to evaluate the efficacy of imazapyr/triclopyr tank mixtures on species known to be tolerant or resistant to foliar sprays of imazapyr. For that purpose, a fixed amount of Chopper EC was added to varying amounts of Garlon 4 with one treatment having Chopper EC with Weedone 170. An untreated check and Garlon 4 applied alone provided a basis for evaluations of the mixtures. Table 1 has a complete listing of treatments. A total of three species known to be "resistant" to imazapyr and three species deemed "susceptible" to imazapyr were treated under the auspices of this project at each study location (table 2).

Project "B" was designed to evaluate the addition of increasing amounts of Chopper EC to a fixed amount of Garlon 4. In this project, imazapyr was applied alone and with Weedone 170 to compare with an untreated check and Garlon 4 applied alone (table 3). The species used in this project are listed in table 4.

Project "C" was designed to evaluate the efficacy of reduced rates of Chopper EC mixed with varying amounts of Garlon 4. An untreated check was included to provide a basis for evaluation (table 5) and the species included in the study are listed in table 6.

All treatments for the three projects were installed at two study locations-near Clemson, SC, and near Starkville, MS. In South Carolina, all species were found at one location. In Mississippi, four sites were utilized in order to

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Table l-Treatments used in Project "A"

Treatment number	Chopper EC	Garlon 4	Weedone 170	Oil
	Herbicide applied			
	- - - - - - - - - - - - - - Percent - - - - - - - - - - - - -			
1	7.8	—	—	92.2
2	7.8	20	—	72.2
3	7.8	15	—	77.2
4	7.8	10	—	82.2
5	7.8	5	—	87.2
6	—	20	—	80.0
7	7.8	—	25.0	67.2
8	Untreated check			

Table 2-Species used in Project "A" and location

Resistant species	Location	Susceptible species	Location
Hackberry	MS	White oak	MS
Loblolly pine	MS	Green ash	MS
Eastern redcedar	MS	Boxelder	MS
Loblolly pine	SC	Black cherry	SC
Winged elm	SC	Red oak	SC
Black locust	MS	Dogwood	SC

Table 3-Treatments used in Project "B"

Treatment number	Chopper EC	Garlon 4	Weedone 170	Oil
	Herbicide applied			
	- - - - - - - - - - - - - - Percent - - - - - - - - - - - - -			
1	1.56	20	—	78.44
2	3.125	20	—	76.875
3	4.70	20	—	75.30
4	6.25	20	—	73.75
5	7.80	20	—	72.20
6	—	20	—	80.0
7	7.80	—	25.0	67.20
8	7.80	—	—	92.20
9	Untreated check			

Table 4-Species used in Project "B" and location

Species	Location	Species	Location
White oak	MS	Red oak	SC
Sweetgum	MS	Black cherry	SC
Hickory	MS	Loblolly pine	SC
Loblolly pine	MS		

Table 5—Treatments used in Project "C"

Treatment number	Chopper EC	Garlon 4	Oil
	Herbicide applied		
	- - - - - - - - - - - - Percent- - -		
1	1.56	5	93.44
2	1.56	10	88.44
3	1.56	15	83.44
4	3.125	5	91.875
5	3.125	10	86.875
6	3.125	15	81.875
7	4.70	5	90.30
8	4.70	10	85.30
9	4.70	15	80.30
10	Untreated check		

Table 6-Species used in Project "C" and location

Species	Location	Species	Location
White oak	MS	Black locust	SC
Hickory	MS	Winged elm	SC
Green ash	MS	Red oak	SC

obtain the desired species diversity. All four stands were on the Noxubee Wildlife Refuge and included a mixed pine-hardwood site, a bottomland hardwood site, an old field cedar succession site, and a pine natural regeneration site.

All treatments were applied with a CO,-powered backpack sprayer with a 2-foot wand and full cone nozzle. Treatments were applied in February 1994 with evaluations completed in September 1994 and September 1995. During evaluation, each tree was classed as 1 of 10 codes ranging from "no injury" to "completely dead," and the percentage of crown reduction was recorded for all tagged trees.

Data were subjected to analysis of variance with Tukey's Test used to establish significance among the means. Percentages were analyzed following arc syne transformation. Overall, approximately 2,000 stems were tagged and evaluated in this study.

RESULTS AND DISCUSSION

To facilitate presentation of results, each project will be discussed separately. The species deemed "susceptible" in Project "A" included green ash, boxelder, white oak, red oak, black cherry, and dogwood. Overall, all treatments controlled all these species very well except white oak (table 7). It is unknown why the herbicide treatments were less effective on white oak, as that species is typically more susceptible than red oak. The Chopper/oil mixture gave crown reductions of 60 to 100 percent after 2 years depending on the species. If white oak is excluded, all other treatments resulted in at least 90 percent crown reductions, with most treatments resulting in a total kill of all stems. The addition of triclopyr did improve control significantly for green ash, boxelder, and red oak, but not for the other three species. The addition of Weedone 170 did not improve control, and increasing the amount of triclopyr did not improve control on these species.

For the species deemed "resistant" in Project "A," the addition of triclopyr significantly improved control for all species except Eastern redcedar (table 8). Tank mixtures of imazapyr and triclopyr killed all stems of hackberry, loblolly pine, and winged elm. Increasing the amount of triclopyr did not improve control except for black locust, and the addition of Weedone 170 did not improve control except for black locust. Overall, species that have demonstrated resistance to imazapyr foliar spray can be controlled by these basal applications with Eastern redcedar being the exception.

Table 7-Percentage of crown reduction after two growing seasons for susceptible species in Project "A"

Treatment number	A	B	WO	C	D	RO
	Species[a]					
	------------- Percent -------------					
1	72	88	60	90	100	77
2	100	100	93	90	100	100
3	100	100	63	100	100	100
4	100	100	83	100	100	100
5	100	100	57	100	100	100
6	100	100	55	90	100	100
7	100	100	58	100	100	99
8	24	3	20	9	10	3

[a] A=ash, B=boxelder, WO=white oak, C=cherry, D=dogwood, RO=red oak.

Table 8-Percentage of crown reduction after two growing seasons for susceptible species in Project "A"

Treatment number	RC	H	P	E	L	P
	Species[a]					
	------------- Percent -------------					
1	19	52	45	78	88	80
2	25	100	100	100	89	100
3	30	100	100	100	91	100
4	61	100	100	100	81	100
5	13	100	100	100	49	100
6	36	100	100	100	68	100
7	48	90	60	90	99	100
8	20	0	3	0	31	3

[a] RC=redcedar, H=hackberry, P=pine, E=elm, L=locust, P=pine

In Project "B," increasing the amount of imazapyr did not improve control on white oak, hickory, sweetgum, black cherry, red oak, or loblolly pine (table 9). Once again, white oak was the most resistant of the species treated, but adequate control was obtained by all treatments except the imazapyr/oil and imazapyr/Weedone 170/oil combinations. Chopper alone provided excellent control of black cherry, red oak, and loblolly pine, but the addition of triclopyr was necessary to adequately control the other species in the project.

Table g-percentage of crown reduction after two growing seasons for susceptible species in Project "B"

Treatment number	WO	K	S	C	RO	P
	Species[a]					
	------------- Percent -------------					
1	90	100	100	100	100	100
2	86	100	100	100	99	100
3	60	100	80	100	100	100
4	84	100	100	100	100	100
5	92	92	100	100	100	100
6	100	90	100	100	100	100
7	39	83	64	100	87	90
8	11	20	58	100	100	91
9	22	2	22	0	16	9

[a] WO=white oak, K=hickory, S=sweetgum, C=cherry, RO=red oak, P=pine. [a] RC=redcedar, H=hackberry, P=pine, E=elm, L=locust, P=pine.

Results from Project "C" paralleled Project "A" in that white oak demonstrated less response to treatments than the other six species involved. Only three of the nine herbicide mixtures provided adequate control of white oak (table 10). With the exception of white oak, the lowest rates of imazapyr and triclopyr (Treatment 1) resulted in 100 percent control of all species in the project. Increasing the rate of imazapyr and/or triclopyr therefore could not improve control on these species. Notable in the results were the responses of loblolly pine, winged elm, and black locust. All are considered "resistant" to imazapyr, and all were effectively controlled by the lower rates of Chopper and Garlon mixtures.

SUMMARY AND CONCLUSIONS

A compilation of the percentage of control obtained for all species in the three projects is found in table 11. Of the 13 species involved, only Eastern redcedar proved strongly resistant to these basal treatments. One treatment (#4 in Project "A") did provide 60 percent control, but the overall average of 33 percent control is less than desirable. White oak was consistent in the response in all three projects in that @ 70 percent control was obtained. The other 11 species treated all proved susceptible to various treatments in this study.

Examination of the responses to individual treatments revealed trends of interest. It was clearly demonstrated that imazapyr is effective as a basal treatment. Based on examination of the varying rates in the three projects, increasing the rate of imazapyr did not result in improved control on the species in this study. The addition of triclopyr to imazapyr improved control on many of the study species, but increasing the amount of triclopyr did not

Table IO-Percentage of crown reduction after two growing seasons for susceptible species in Project "C"

Treatment number	Species[a] A	K	WO	P	E	L	RO
	- - - - - -	- - - -	Percent	- - - -	- - - -	- - - -	- - - -
1	100	100	75	100	100	100	100
2	100	92	62	100	100	69	90
3	100	92	70	62	100	100	100
4	100	90	56	90	100	78	91
5	100	100	90	82	100	88	90
6	100	100	90	64	100	100	100
7	100	100	90	90	100	98	100
8	100	92	55	100	100	100	100
9	100	98	63	90	100	97	100
10	0	0	16	0	0	56	0

[a]A=ash, K=hickoty, WO=white oak, P=pine, E=elm, L=locust, RO=red oak.

Table II-Overall control after two growing seasons for species in the study (all treatments in all projects).

Species	Project "A"	"B"	"C"
	- - - -	*Percent*	- - - -
Green ash	*96*		100
Boxelder	*98*		
White oak	*67*	*70*	*72*
Black cherry	*96*	*100*	
Dogwood	*100*		
Red oak	*97*	*98*	*97*
Sweetgum		*88*	
Hickory		*86*	*96*
Hackberry	*92*		
Loblolly pine	*94*	*98*	*86*
Winged elm	*97*		*100*
Black locust	*81*		*92*
Eastern redcedar	*33*		

consistently improve control-an actual decrease in control occurred in some treatments. The addition of Weedone 170 did not consistently or significantly improve control of species in this study. Perhaps of greatest interest was the observation that basal applications using imazapyr controlled species considered "resistant" to foliar sprays of imazapyr. Eastern redcedar remained resistant to these basal treatments, but fire is effective on this species when used in forest management.

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IMPACT OF HERBACEOUS WEED SUPPRESSION ON LOBLOLLY PINE SAWTIMBER ROTATIONS

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Abstract-A study was initiated in 1957 to determine the long-term effect of herbaceous weed competition on growth and development of loblolly pine. Seedlings were planted at a density of 1,200 trees per acre (TPA) and three weed suppression treatments were applied: no weed suppression (Check), 1 year of weed suppression (1YS), and 2 years of weed suppression (2YS). By age 20, pine stocking density was similar for all treatments averaging 850 TPA. 2YS means merchantable volume was 2,940 cubic feet per acre (ft^3/acre), which exceeded Check and 1YS mean volumes by 540 and 260 ft^3/acre. Between ages 20 and 39, all treatment plots were thinned to similar pine stocking densities at ages 20, 25, and 34. The residual stand stocking densities for the respective ages were 225, 100, and 50 TPA. Total merchantable volume at age 39 averaged 4,400, 4,600, and 4,840 ft^3/acre for the Check, 1YS, and 2YS treatments, respectively merchantable volume growth from age 20 to age 39 did not differ among treatments, averaging 1,980 ft^3/acre. Early herbaceous weed competition did impact the wood yield distribution among products. At age 39, respective product volume yields for the Check, 1YS, and 2YS treatments were pulpwood 1,530, 1,410, and 1,400 ft^3/acre; chip-n-saw 850, 1,270, and 1,410 ft^3/acre, and sawtimber 2,020, 1,940, and 2,030 ft^3/acre. Check summed chip-n-saw and sawtimber volume was 340 and 570 ft^3/acre less than 1YS and 2YS treatment volume totals. The highest internal rate of return for all treatments occurred at age 34, and was 5.9, 6.3, and 6.6 percent for the Check, 1YS, and 2YS, respectively.

INTRODUCTION

Initial growth and development of loblolly pine (*Pinus taeda* L.) plantations can be improved by limiting the negative impact of herbaceous weed competition. Herbaceous weed suppression during the first growing season improves survival rate (Metcalf 1986) and increases height and diameter growth (Clason 1984, Miller and others 1987). Seedling growth responses attributed to herbaceous vegetation control increased merchantable volume yields 128 percent in IO-year-old loblolly plantations (Creighton and others 1986). Although a positive response to weed suppression is discernible in sapling-size plantations, the long-term effect on plantation growth and yield is not known.

In a loblolly pine plantation established as a planting site fumigation study, Hansbrough and others (1964) found seedling growth differences between treatments. By age 6, seedling height and diameter growth on a methyl bromide treatment exceeded the control treatment by 4.5 feet (ft) and 0.9 inches (in.). Seedling growth differentials were attributed to herbicidal activity of methyl bromide because weed and grass growth was suppressed for 2 years after treatment. Since tree growth was measured periodically between ages 6 and 39, a substantial data set was created for tracking long-term treatment growth and development patterns. Therefore, this data set will be used to examine efficacy of herbaceous weed suppression on plantation growth and development for rotation ages of 20, 25, 30, 34, and 39.

METHODS AND PROCEDURES

A study was initiated in 1957 to determine effects of planting site fumigation on growth and development of loblolly pine. The experimental area was an old field 4 acres in size having Shubuta and Savannah fine sandy loam soils and a site index of 64 ft at age 25. Prior to planting seedlings, the area, which had been withdrawn from cultivation for many years, was cleared and then disked several times to eliminate encroaching woody vegetation. Seedlings were planted at a spacing of 6 by 6 feet on O.l-acre plots. Treatments included: no weed suppression (Check), 1 year of weed suppression (1YS), and 2 years of weed suppression (2YS). Soil fumigates used for treating the weed suppression plots were 1,3-dichloropropene-I, 2-chloropropane for the 1YS treatment and 98 percent methyl bromide + 2 percent chloropicrin for the 2YS treatments. Fumigation treatments were allowed to dissipate for 1 month prior to planting. Measurement plots, consisting of 6 rows with 10 seedlings, were designated in the center of each treatment plot. Seedling mortality was observed monthly during the first growing season and annually thereafter. Diameter at breast height (d.b.h.) and height growth were measured annually through age 10, and at ages 14, 17, 20, 25, 30, 34, and 39. Between ages 20 and 39, all treatment plots were thinned at ages 20, 25, and 34 to residual densities of 225, 100, and 50 TPA, respectively. Pine merchantable volume was computed to a 3.0-inch inside bark diameter using a pooled equation reported by Van Deusen and others (1981) and saw-timber volume (Doyle Scale) was determined from saw-timber cubic foot volume using a published conversion factor (Williams and Hopkins, 1968). All growth data were analyzed with ANOVA procedures.

RESULTS

Plantation Growth

Merchantable volume growth differences were detected among treatments at age 20 (table 1). Although 2YS treatment stocking density was 80 and 60 TPA less than the Check and 1YS treatments at age 20, 2YS treatment

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Table I-Mean stand growth attributes by treatment from ages 20 to 39

Treatment	Stocking density	D.b.h.[a]	Height	Basal area	Merchantable volume Total	Pulpwood	C-N-S[b]	Sawtimber
	TPA'	In	Ft	Ft^2/acre	Ft^3/acre			Bd.ft./acre[d]
Age 20 standing								
Check	901	5.7	47	155	2,400	1,560	840	—
1 year sup	881	5.9	48	167	2,680	1,500	1,150	80
2 year sup	821	6.3	49	175	2,940	1,470	1,430	100
Age 20 harvest								
Check	691	5.2	45	97	1,350	1,350	—	—
1 year sup	625	5.6	46	105	1,520	1,200	320	—
2 year sup	588	5.8	47	107	1,620	1,150	470	—
Age 20 residual								
Check	232	7.1	48	63	1,050	210	840	—
1 year sup	256	6.9	50	67	1,160	300	830	80
2 year sup	233	7.6	52	74	1,320	320	960	100
Age 25 standing								
Check	222	8.1	59	73	1,530	230	1,150	350
1 year sup	245	8.0	60	78	1,670	260	1,230	470
2 year sup	227	8.6	63	81	1,790	280	1,190	830
Age 25 harvest								
Check	127	7.7	57	32	630	130	500	—
1 year sup	154	7.4	59	38	770	160	610	—
2 year sup	134	8.2	60	37	780	190	590	—
Age 25 residual								
Check	95	8.8	62	41	900	100	650	350
1 year sup	91	8.8	64	40	900	100	620	470
2 year sup	93	9.3	65	44	1,010	90	600	830
Age 30 standing								
Check	95	10.4	65	56	1,300	70	500	1,980
1 year sup	91	10.4	65	54	1,290	70	460	2,140
2 year sup	93	10.7	67	59	1,430	70	470	2,580
Age 34 standing								
Check	95	11.9	70	74	1,830	60	400	4,310
1 year sup	91	11.8	70	71	1,780	60	400	4,230
2 year sup	93	12.0	71	75	1,930	60	390	5,020
Age 34 harvest								
Check	39	11.0	69	26	630	30	190	1,180
1 year sup	40	10.9	70	26	660	30	200	1,220
2 year sup	46	10.8	69	30	750	40	230	1,420
Age 34 residual								
Check	56	12.4	70	48	1,200	30	210	3,130
1 year sup	51	12.5	70	45	1,120	30	200	3,010
2 year sup	48	13.3	73	45	1,180	20	160	3,600
Age 39 standing								
Check	56	14.7	75	67	1,790	20	160	6,400
1 year sup	51	15.1	74	63	1,650	20	140	6,130
2 year sup	48	15.7	75	64	1,690	20	120	6,660

[a] Diameter at breast height
[b] Chip-n-saw.
[c] Trees per acre.
[d] Doyle Scale.

merchantable volume was significantly greater than, the other two treatments. The growth differentials for the check and 1YS treatments were 540 and 260 cubic feet per acre (ft^3/acre), respectively. Between ages 20 and 39, treatment merchantable volume growth did not differ and averaged 1,940 ft^3/acre. Periodic merchantable volume growth between thinning interventions did not differ among treatments. Mean volume growth from ages 20 to 25, ages 25 to 34, and ages 34 to 39 was 490, 900, and 550 ft^3/acre. Thus, at each rotation age, 2YS merchantable volume yield exceeded the check yield by 500 ft^3/acre.

Herbaceous weed treatment had a significant impact on product volume distribution. Pulpwood and chip-n-saw (C-N-S) volumes at age 20 were similar to total pulpwood and C-N-S volumes at age 39 (table 1). Pulpwood volume did not differ among treatments at either age, averaging 1,500 and 1,450 ft^3/acre at ages 20 and 39. 2YS C-N-S volume was significantly greater than the Check at both ages. Respective treatment volumes at ages 20 and 39 were 840 and 1,430 ft^3/acre, and 850 and 1,410 ft^3/acre. Although 1YS and 2YS treatment had some sawtimber volume at age 20, sawtimber ingrowth did not begin until age 25. By age 39, sawtimber volume growth averaged 2,000 ft^3/acre for all treatments. However, total lumber volumes (board foot, Doyle Scale) differed among treatments with Check, 1YS, and 2YS averaging 7,580, 7,350, and 8,080 board feet (bd. ft.) per acre, respectively.

Crop Tree Growth

At age 20, the equivalent of 50 crop TPA was Identified on each treatment plot using d.b.h., tree form, and spatial position as selection criteria. Age 20 treatment crop tree d.b.h., height, and basal area differed significantly among treatments (table 2). Mean 1YS and 2YS treatment d.b.h., height, and basal area exceeded the Check by 0.5 inches, 3 feet, and ,046 ft^2, respectively. Except for height, which averaged 75 feet for all treatments, 2YS crop tree total

Table 2-Mean crop tree growth attributes by treatment from age 20 to 39

Treatment	Stocking density	D.b.h.[a]	Height	Basal area	Merchantable volume: Total	Pulpwood	C-N-S[b]	Sawtimber
	TPA[c]	*In.*	*Ft.*	*Ft²*	- - - - - - - - *Ft³*	- - - - - - - -		
Age 20								
Check	50	7.8	56	0.337	6.685	1.175	5.510	—
1 year sup	50	8.2	57	0.374	7.621	2.166	5.455	1.062
2 year sup	48	8.4	59	0.392	8.184	2.111	6.073	1.030
Age 25								
Check	50	9.3	64	0.473	10.668	0.965	7.429	2.274
1 year sup	50	9.5	66	0.495	11.525	0.970	7.109	3.447
2 year sup	48	9.9	66	0.544	12.703	0.878	6.223	5.603
Age 30								
Check	50	11.0	66	0.667	15.685	0.707	4.171	10.807
1 year sup	50	11.1	68	0.679	16.476	0.722	4.232	11.521
2 year sup	48	11.6	69	0.743	18.141	0.656	3.989	13.496
Age 34								
Check	50	12.4	70	0.848	21.114	0.586	3.706	16.822
1 year sup	50	12.5	70	0.865	21.666	0.579	3.800	17.286
2 year sup	48	13.3	73	0.972	25.419	0.526	3.432	21.461
Age 39								
Check	50	14.7	75	1.192	31.638	0.424	2.877	28.336
1 year sup	50	15.1	74	1.258	33.058	0.401	2.726	29.931
2 year sup	48	15.7	75	1.360	36.333	0.374	2.557	33.354

[a] Diameter at breast height
[b] Chip-n-saw.
[c] Trees per acre.
[d] Doyle Scale.

growth between ages 20 and 39 surpassed both the Check and 1YS treatments. Mean crop tree d.b.h., basal area, merchantable volume, and saw-timber volume growth differentials between the 2YS and the other two treatments were 0.4 inches, 0.1 ft^2, 2.95 ft^3, and 3.72 ft^3, respectively. Periodic tree basal area growth between thinning interventions differed among treatments. Mean basal area growth for the Check, 1YS, and 2YS treatments from ages 20 to 25, ages 25 to 34, and ages 34 to 39 was 0.136, 0.121, and 0.152 ft^2; 0.375, 0.370, and 0.428 ft^2; and 0.344, 0.393, and 0.388 ft^2, respectively. Crop trees on the 2YS treatment plots performed better after thinning than crop trees on the Check or 1YS treatment plots.

Financial Comparisons

The long-term financial impact of herbaceous weed suppression was evaluated by comparing the treatment internal rates of return (IRR) for rotation ages of 20, 25, 30, 34, and 39. Cost and revenue data were standardized for all treatments. Cost data obtained from Dubois and others (1995) included aerial site preparation with a burn: $96.00 per acre; planting 1,200 TPA: $111.60 per acre; aerially applied herbaceous weed suppression: $36.00 per acre; thinning preparation: $16.00 per acre; and annual tax and administration cost: $3.50 per acre. A land value of $300.00 per acre was added as a rotation establishment cost. Revenue data obtained from Odom and Frey (1995) included pulpwood: $0.28 per ft^3; C-N-S: $0.99 per ft^3; and saw-timber: $0.361 per bd. ft. (Doyle Scale). A land value of $300 per acre was added at the end of the rotation as a revenue. All timber revenue was computed as the highest valued product.

For each rotation age, the IRR was directly related to the intensity of herbaceous weed suppression (table 3). Since treatment pulpwood and saw-timber volumes were similar for all rotation ages, treatment revenue differences were attributed to the C-N-S volume differentials detected at age 20. Under the conditions of this study, 1YS and 2YS treatment optimum rotation was 34 years; the IRR for the respective treatments were 6.35 and 6.58 percent. The financial results could have been altered by shortening the 2YS treatment rotations, thinning before age 20, or using a lower planting density.

Table 3-Treatment internal rate of return by rotation age

Treatment	Rotation age				
	20	25	30	34	36
	Percent				
Check	5.30	5.40	5.50	5.88	5.89
1 year sup	5.98	6.10	6.14	6.35	6.12
2 year sup	6.41	6.33	6.34	6.58	6.24

CONCLUSIONS

Two years of herbaceous weed suppression had a positive impact on plantation growth and development for rotation ages of 20, 25, 30, 34, and 39.

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COMPETITION CONTROL FOR HARDWOOD PLANTATION ESTABLISHMENT

A.W. Ezell and A.L. Catchot, Jr.'

Abstract-Sulfometuron methyl was applied at both pre-emergent and postemergent timings in newly established oak and ash plantings. Species involved in the study include cherrybark oak, Nuttall oak, Shumard oak, water oak, willow oak, white oak, and green ash. Treatments were evaluated for both competition control and crop tolerance. First-year survival for treated and untreated areas was also evaluated for all species. Results indicate that effective competition control can be obtained with over-the-top treatments in hardwood plantations. No crop damage was exhibited in any of the pre-emergent treatments. However, postfoliation application resulted in foliar necrosis on some species and complete mortality for white oak. Overall, first-year survival for all species was increased by approximately 12 percent.

INTRODUCTION

For years, interest in managing and regenerating desirable species of hardwoods has been increasing. Paramount to that subject area has been the concern over cost-effective oak regeneration practices. Thousands of acres were artificially regenerated to hardwoods under the auspices of the Conservation Reserve Program with highly variable results. In many cases, the direct seeding efforts were failures in terms of establishment, and though planted seedlings have higher establishment rates, survival is often much lower than desirable. While a number of factors will directly affect the survival of hardwood planting, especially seedling quality and planting job quality, control of competing vegetation is a major concern, especially in areas of established herbaceous cover. Miller (1993) published a comprehensive overview of all the herbicides that were appropriate for oak culture. While pre-plant and directed spray applications are necessary components of different regeneration strategies, it was the focus of the current work to evaluate postplant, over-the-top applications of a suitable product. The prime candidate for such an application is sulfometuron methyl, which is labeled for such use when applied prior to bud break of the oak.

Rhodenbaugh and Yeiser (1994) reported tolerance of eight hardwood species to pre-plant and postplant (pre-budbreak) Oust® application. Decreases in survival and increases in injury were attributed to site factors other than Oust® treatment for all oak species except cherrybark.

OBJECTIVE

The objectives of the study were as follows:

- To evaluate competition control efficacy of pre-emergent applications of Oust® in an abandoned agricultural planting site.
- To evaluate any first-year survival differences in oak species planted in treated vs. untreated plots.
- To evaluate the effect of postfoliation applications of sulfometuron methyl to selected oak species.

MATERIALS AND METHODS

A total of six oak species and green ash were planted on an abandoned agricultural site approximately 6 miles north of Starkville, MS. Species included in the study included cherrybark oak, Nuttall oak, Shumard Oak, water oak, willow oak, white oak, and green ash. A complete listing of the common and scientific names follows:

Common name	Scientific name
Cherrybark oak	*Quercus pagoda* Raf.
Nuttall oak	Q. *nuttallii* Palmer
Shumard oak	Q. *shumardii* Buckl
Water oak	Q. *nigra* L.
Willow oak	Q. *phellos* L.
White oak	Q. *alba* L.
Green ash	*Fraxinus pennsylvanica* marsh

The site had been out of cultivation for 4 years and herbaceous vegetation completely covered the planting area. All seedlings were planted in January 1996.

In early March, two rates of Oust® [2 ounces (oz.) per acre and 4 oz per acre] were applied over the top of the planted seedlings. Three replications of each rate were completed for each species in this pre-emergent application in a completely randomized block design. All spraying was completed with a CO, powered backpack sprayer with a hand held wand, a TK 2.5 floodjet nozzle, and a total spray volume of 20 gallons (gal) per acre. The planted row served as the center for the 6-foot band application. All treatments were evaluated at 14 days after treatment (DAT), 30 DAT, 60 DAT, and 90 DAT intervals for both crop tree damage and competition control. In December 1996, first-year survival was recorded.

In late April, after all trees were fully foliated, Oust® was applied over the top of cherrybark oak, Nuttall oak, Shumard Oak, white oak, and green ash at a rate of 2 oz. per acre. These plots were evaluated at 30 DAT and 60 DAT for crop tree damage and in December 1996, for first-year survival. While not part of the original project protocol or labeled application, the availability of seedlings provided an opportunity to gain insight into the perennial question regarding postfoliation applications. Competition control in treated areas was assessed as a percentage of clear ground in 5-percent increments. Crop tree injury was evaluated as a percentage of foliar necrosis, and all foliage

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was examined for chlorosis. Percentage measurements were subjected to arc syne transformation prior to analysis of the variance.

RESULTS AND DISCUSSION

Both rates of herbicide gave excellent competition control for 60 DAT. No significant difference for control was observed until 90 DAT, when the 4 oz. rate demonstrated a greater residual effect; but at that time, the 2 oz. rate plots averaged 30 to 35 percent clear (see table 1). Overall, the treatments yielded good broadleaf control with the problem species being broomsedge and selected *Panicum.*

Crop Tree Tolerance (Pre-emergent)

No injury was noted on any seedlings resulting from herbicide application. Overall, the seedlings appeared thrifty, foliated fully, and established.

Crop Tree Tolerance (Postfoliation spray)

Species demonstrated different tolerance when evaluated 30 DAT. The cherrybark oak had no visible necrosis and any possible chlorosis was extremely slight. Nuttall and Shumard oaks both exhibited leaf margin necrosis across the crown, but new leaves continued to form and the trees continued to grow. Green ash response varied by the position of the apical leader in relation to the spray. If the herbicide was totally over the top of the seedling, leaf burn, necrosis, and leaf mortality were much more extensive than on the stems that had received spray only on lower crown positions. Damage ranged from 20 to 80 percent leaf burn. White oak exhibited a consistent response in that all stems were dead in the treatment plot.

Survival

First-year survival was very consistent across all replications (treatments) for all species (see table 2). All species had greater than 83-percent survival at the end of the first growing season in the treated plots. No significant survival difference was found in any comparison of herbicide application rate. Even through the 4 oz. rate provided greater residual control, the 2 oz. rate was sufficient on this site for establishment. By comparison, the untreated plots averaged 60 to 70 percent survival, which gave an overall increase of 213 percent survival to seedlings with competition control in this study. We fully expect species/site suitability to affect impact survival and growth in coming years as is normal with hardwood plantations. In what could be indicative of the future of this planting, a screening trial was completed on these same species of oak and ash 5 years ago on this site. While Nuttall oak and green ash have the highest 5-year survival rate (92 to 87 percent, respectively), all species exhibit @20 percent greater survival in plots receiving herbicide treatments than those in untreated areas.

Table I- Percentage of clear ground in Oust® field trial treatment plots by evaluation time (average of all replications)

	Time of evaluation (days after treatment)				
Herbicide rate	14	30	60	90	120
2 oz./acre	100	100	*87*	*33*	*20*
4 oz./acre	100	100	93	*63*	*52*
Untreated	93	67	10	5	5

Table 2-First year survival in Oust® pre-emergent application study (average all reps)

Species	Herbicide rate	Survival
	Oz. *per acre*	*Percent*
Cherrybark	2	*85*
	4	*87*
Nuttall	2	*90*
	4	*92*
Shumard	2	*87*
	4	*87*
White	2	*83*
	4	*87*
Water	2	*87*
	4	*90*
Willow	2	*85*
	4	*88*
Untreated (all species)	—	*60-70*

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DOES PARAQUAT CAUSE STEM SWELLINGS IN FIRST-YEAR COTTONWOOD SAPLINGS?

Theodor D. Leininger and Curtis S. McCasland[1]

Abstract-This study was prompted by the occurrence, in 1995, of stem swellings on about 80 to 90 percent of all first-year shoots of eastern cottonwood (*Populus deltoides* J. Bartam ex Marsh.) after an application of paraquat to control weeds in a 65-hectare plantation near Fitler, MS. Paraquat was applied in spring and summer 1996, respectively, to the bases of two different sets of first-year cottonwood saplings at 0, 0.25, 0.5, 1 .0, and 2.0 times the normal rate used for weed control to determine a dose-response relationship for paraquat and the occurrence of stem swellings. The occurrence of swellings 2, 3, and 4 months after the spring treatment was positively related to paraquat dose. Swellings occurred less often, and only at the 1 .O and 2.0 rates, after the summer treatment. Sapling survival was related to paraquat dose for the spring application ranging from 97 percent in the control group to 18 percent for saplings treated with the 2.0 rate. Paraquat dose did not affect sapling survival after the summer application. Four months after the spring treatment, stem diameters of saplings treated with 1 .O and 2.0 rates were 67 and 38 percent, respectively, of those of the control saplings. Stem heights showed similar responses. Summer treatments had little effect on diameters and heights of saplings. Use of paraquat to control weeds in first-year cottonwood plantations should include provisions to reduce or eliminate contact with green stem tissues.

INTRODUCTION

In mid-June 1995, an estimated 80 to 90 percent of all first-year shoots of cottonwood (*Populus deltoides* J. Bartam ex Marsh.) in a 65-hectare (ha) plantation near Fitler, MS, exhibited IO- to 15-centimeter (cm) long swellings located 3 to 10 cm above the attachment of the shoot to the cutting. The swellings were 2 to 2.5 times the normal stem diameter and were fusiform in shape. During cultivation in mid-June, an estimated 15 to 20 percent of the shoots broke just below the swellings where the stems were brittle. Swellings first appeared in mid-May following an application of paraquat to stem bases in early May to control weeds. The spray rig used in this application was not set up to shield stem bases from being sprayed. Cottonwood clones from Fitler and Stoneville, MS, and one of Texas origin, were affected. No effort was made to determine differences in cottonwood clones in manifesting the swellings. Paraquat damage was evident as black, sunken, oval lesions measuring about 0.5 cm by 1.0 cm on portions of the shoots above the swellings. Various causes for the swellings were considered including insects, diseases, weather, and chemical drift from nearby farms, but none of these provided a satisfactory explanation. Although the evidence was circumstantial, swellings appeared related to the application of paraquat.

Subsequent discussions with other plant pathologists and herbicide specialists revealed similar injuries on branches of loblolly pines exposed to paraquat spray drift, and on cotton from an incorrect application of paraquat. Paraquat is a contact herbicide which is absorbed quickly by green plant tissue where it reacts with the photosynthetic process producing free radicals; these destroy plant cells and membranes and cause the death of tissues within hours (Rice 1992). A hypothesis emerged which held that young, green phloem and bark tissues were killed by paraquat, thereby removing the conduit for photosynthates to be transported to roots. Photosynthates accumulated in stems distal to the dead tissue, thereby causing swellings and brashness. This phenomenon is known in woody ornamental production as "wire-tag disease," in which case a physical barrier (e.g., a wire tag) cuts into the phloem restricting the downward movement of photosynthates. Swellings occurred less frequently on first-year cottonwood saplings treated with paraquat in August 1995, presumably after bark tissue was more mature.

Paraquat was used by the grower, under the "trees and vines" section of the Federal label, to control weeds in first-year cottonwood plantations for several years before these swellings occurred. It was an important management tool because it was the only broad-spectrum herbicide that effectively controlled early-summer annual weeds, such as morning-glory (*Convolvulus* L. spp.), ragweed *(Ambrosia* L. spp.), pigweed *(Amaranths* spp. L.), cocklebur (*Xanthium* L. spp.), *Sesbania* Scop. spp., and primrose *(Primula* L. spp.) at a low cost while posing a minimal risk to cottonwood health. Paraquat was not applied to sapling bases to control weeds during 1996 because of concern over the occurrence of these stem swellings. To address the growers' concern, this study was done to determine the concentration of paraquat at which bark and phloem were killed, thereby causing photosynthates to accrete as swellings on lower stems of first-year cottonwood saplings. A second objective was to determine whether swellings on first-year cottonwood saplings could be avoided by applying paraquat later in the season after bark tissue had become more mature.

This research also addresses an area of wider concern within the forestry community, that of having useful chemicals to control annual and perennial weeds in hardwood plantations. Commercial hardwood interests are more and more considering plantations as one key to meeting increased demands for hardwood fiber, and are looking to researchers to address questions of feasibility

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(Anonymous 1996). It is likely that more studies like this will need to be done to meet the needs of hardwood plantation growers in the private, as well as public, sectors.

METHODS

Experimental Design and Approach

The cottonwood saplings used in this study were planted as cuttings in December 1995. In February 1996, a tank mix of oxyfluorfen [80 ounce per acre] and paraquat [I quart per acre] was sprayed in 6-foot bands down the rows and over the top of the dormant cuttings. Weeds growing between rows were controlled using a disc harrow before paraquat was applied to the bases of saplings. Two times during the growing season after treatments were installed, a disc harrow was used for weed control. The disc harrow was driven between rows in one direction and then again between rows at a 90-degree angle to the first pass. These conditions replicated, as nearly as possible, the cultural conditions to which the 1995 saplings were exposed.

Treatments were set up as a two-way factorial in a randomized complete block design with 10 (two applications x five dose levels) factor-level combinations in each of three blocks. Applications of 0, 0.25, 0.5, 1, and 2 times the grower's normal operational rate of paraquat (24 ounces per acre as 37 percent paraquat dichloride a.i.) were made to the bases of first-year cottonwood saplings on June 17 (spring) and August 19 (summer) 1996. The control (0) treatment contained only the nonionic surfactant in water that was used to apply the paraquat. Paraquat was applied using a modified, conventional, farm spray rig outfitted with two 8004 flat-fan nozzles on both sides of each row of saplings. Two rows were sprayed simultaneously using a tractor speed of 4.8 miles per hour (mph) and a tank pressure of 10.5 pounds per square inch (psi) adjusted to produce relatively large droplets and avoid drift.

Each treatment was applied to 50 saplings, in 2 adjacent rows of 25 saplings each, planted in a 12 foot by 12 foot spacing. There was a total of 1,500 saplings on 5 acres. The study occupied about 12 acres, including buffers around treated areas, within a 100-acre plantation of first-year cottonwood saplings. Saplings were half-sib, first generation, improved clonal material that originated from Mississippi or Texas. It was not possible to determine clonal responses to paraquat because no record was kept of which clones were planted in the study area. The soil of the study area was of the Sharkey series.

Biological Measurements

Initial heights of saplings in the spring treatments were measured 8 days after spraying. The presence or absence of swellings was recorded on the dominant shoot of each sapling. Stem diameters were measured 10 cm above the ground. The widest diameter of each recorded swelling was measured. Weed control around each sapling was measured by estimating the percentage of area covered by weeds in a 0.5 square meter (m^2) plot centered around the sapling base. Sapling heights from the ground to the tip of the dominant leader were recorded, as were the occurrence of swellings, swelling diameters, stem diameters, percentage of weed cover, and survival for each sapling at l-month intervals following spring and summer applications. Data were taken until October 17, 2 months after the summer treatments. Biological measurement data were analyzed using a three-way analysis of variance procedure.

RESULTS AND DISCUSSION

Swelling Occurrence and Paraquat Dose

One month (July) after the spring application of paraquat, swellings occurred on 27 (or 7 percent) of the surviving saplings (fig. 1). Swellings occurred on saplings in all four paraquat treatments; no swellings were recorded on control saplings. At 2, 3, and 4 months after the spring application of paraquat, there was a clear response to dose expressed as percentages of swellings on paraquat-treated saplings. The total number of swellings on surviving saplings was about the same in July and August, but decreased in September and October. These decreases were due to diameter growth over time which tended to obscure swellings measured previously on some saplings. The percentages of saplings with swellings recorded after the spring treatment (2 to 27 percent) were less than the estimated 80 to 90 percent of saplings with swellings in 1995. One month (September) after the summer application of paraquat, there were swellings on six (or 1 percent) of the surviving saplings treated at the 1.0 (n=2) and 2.0 (n=4) rates. No swellings were recorded on saplings in 0, 0.25, or 0.5 treatments. In October, one sapling exposed to the 1 .O rate and nine saplings exposed to the 2.0 rate were the only saplings with swellings resulting from the summer treatments. These data address

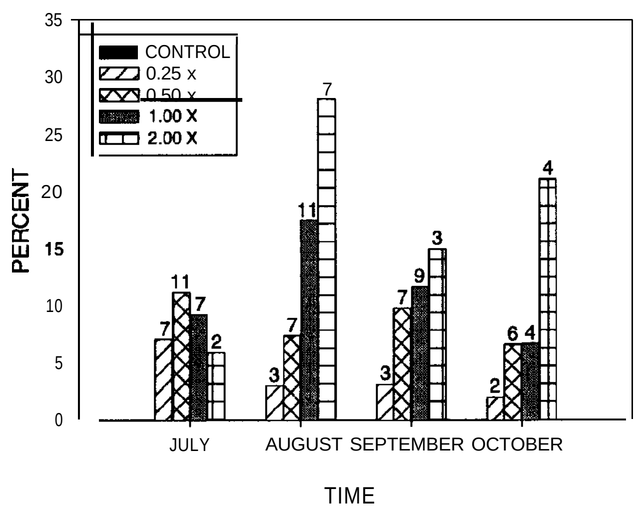

Figure I-Percentages of first-year cottonwood saplings with stem swellings caused by damage to bark tissue following the applications of various doses of paraquat on June 17. Swelling occurrences were assessed at l-month intervals. The number above each percentage bar is the actual number of swellings counted for that treatment. Doses are based on a 1 .0 rate of 24 ounces per acre.

the first objective of the study by showing that paraquat, even at the 0.25 rate, caused swellings on first-year cottonwood saplings. Further, they show a relationship between paraquat dose and the occurrence of swellings. These data also address the second objective of the study since the occurrences of swellings were less when paraquat was applied 2 months later in the summer (August) after bark tissues were more mature than during the spring application (June).

While the occurrence of swellings was related to dosage, the diameters of swellings generally were not related to dosage in either season, with the exception of saplings treated with the 2.0 rate. In 12 of 14 cases, swelling diameters at the 2.0 rate were less than those at other rates. It appeared that tissue damage was so severe at the 2.0 rate that overall sapling growth, including swelling size, was affected.

Sapling Survival and Paraquat Dose

Sapling survival following the spring application was affected by paraquat dose and ranged from 97 percent for control saplings to 18 percent for saplings treated with the 2.0 rate (fig. 2). This dosage response was inversely related to sapling heights measured 8 days after application (fig. 3). The 2.0 rate of paraquat killed all saplings less than or equal to 0.4 meters (m) tall, whereas the 0.25 rate killed saplings 0.15 m or less. Those differences were statistically significant. Paraquat dose had little effect on sapling survival after the summer application with near 100 percent survival for saplings in control and paraquat treatments (fig. 2). Factors that probably were important in the dose response and height inverse relationship following the spring treatments included spray application height, spray drift height, and the relative response of bark tissues to various paraquat doses. The near total survival following the summer application indicated the difference in bark tissue maturity, and thus relative susceptibility to paraquat damage, between the groups of saplings treated in spring and summer.

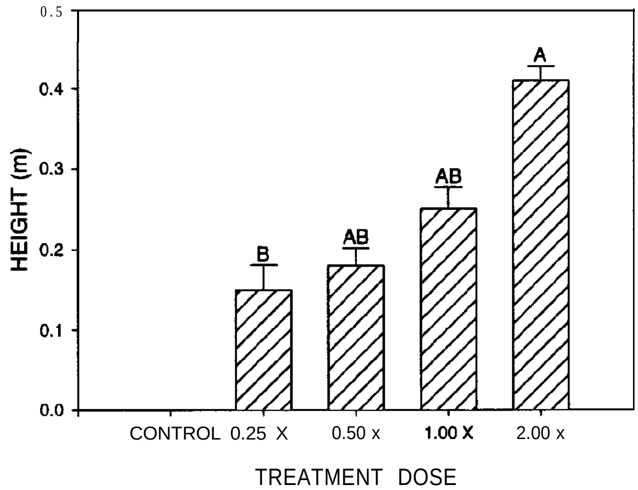

Figure 3-Average heights and standard errors of first-year cottonwood saplings killed by paraquat of various doses. Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different heights, at P=0.5, tested by Tukey's W Procedure.

Stem Heights and Diameters and Paraquat Dose

Average heights of saplings treated in June and measured 3 months later decreased in response to increasing paraquat dose (fig. 4). Saplings not treated with paraquat

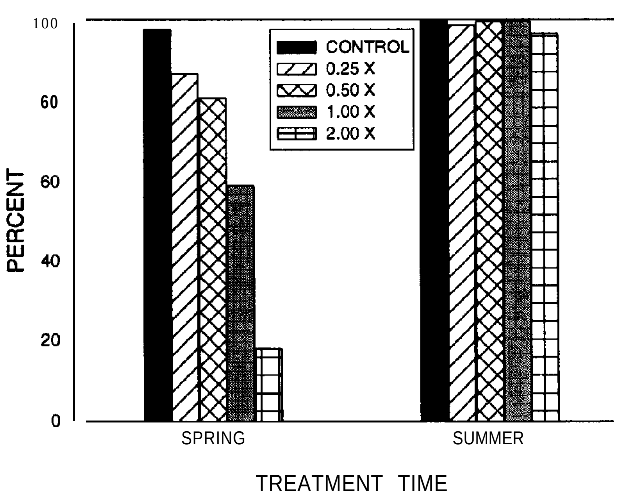

Figure 2-Percent survival of first-year cottonwood saplings evaluated 1 month after the application of various doses of paraquat on June 17 (spring), and 1 month after the application of the same doses of paraquat on August 19 (summer). Doses are based on a 1.0 rate of 24 ounces per acre.

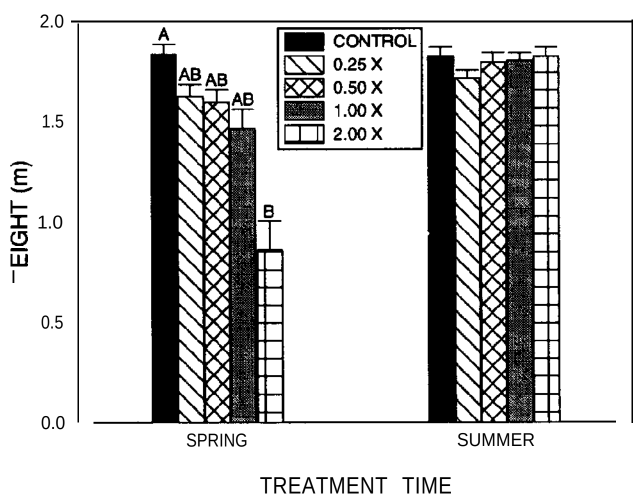

Figure 4-Average stem heights and standard errors of first-year cottonwood saplings measured in mid-September resulting from application of various doses of paraquat on June 17 (spring), or application of the same doses of paraquat on August 19 (summer). Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different heights, at P=0.5, tested by Tukey's W Procedure.

were taller, on average, than saplings treated with the 1 .O and 2.0 rates of paraquat, but were not significantly taller than those treated with the 0.25 and 0.5 rates. There were no treatment differences among average heights of saplings treated in August and measured 1 month later (fig. 4). Average heights of all summer-treated saplings were approximately equal to average heights of spring-treated control saplings. Stem diameters of saplings treated in June and measured 3 months later also decreased as paraquat dose increased (fig. 5). Average stem diameters of control saplings were greater than those of saplings treated with the 1 .O and 2.0 rates of paraquat, but were not statistically different than diameters of saplings treated with the 0.25 and 0.5 rates. The smaller average diameter of saplings treated with the 0.25 rate compared with that of control saplings and saplings treated with the 1 .O rate, following the summer application, is explained best by experimental error. This same trend, though not statistically significant, occurred for stem heights following the summer application (fig. 4). Nonetheless, the average diameter of all summer-treated saplings was approximately equal to the average diameter of spring-treated control saplings.

The losses of growth apparent in stem height and diameter data indicate that there is some risk in applying paraquat for weed control before cottonwood sapling bark tissues have matured enough to not be damaged by the herbicide. In this study, the degree of maturation of bark tissues that protected saplings from paraquat damage occurred in the 2 months between the spring (June 17) and summer (August 19) applications. This time period is likely to vary depending on phenology and genetics. For example, the onset of spring was late in 1996 in comparison to the previous year when the first application of paraquat occurred in mid-May. In general, it would be inadvisable to use paraquat around the bases of first-year cottonwood saplings during spring and early summer. Applications made in mid- to late summer are less likely to cause damage to bark tissues. Stem height and diameter data of spring-treated saplings also suggested a threshold of damage starting with the 1.0 rate. Certainly at the 2.0 rate, paraquat damage was severe enough to reduce even the diameters of swellings. September measurements of stem heights (fig. 6) and diameters (fig. 7) of saplings treated in spring were less, at all four paraquat dosage levels, than their counterparts treated in summer; there were no differences between untreated controls. These spring-summer comparisons suggest that a damage threshold occurred at the 0.25 rate.

Weed Control and Paraquat Dose

Higher doses of paraquat tended to decrease the percentage of weed cover around sapling bases (fig. 8). Although paraquat was sprayed once for the spring treatment, the same dose-related trends in weed cover occurred at 1, 2, 3, and 4 months after spraying. The same trend occurred for percentage of weed cover after summer treatments. Although not specifically documented, it was apparent that different species of weeds were present around sapling bases during the various measurement times. This is evidenced somewhat by the increased weed cover measured in September and October compared to that measured for July and August following the spring treatments. The initial removal of weeds by paraquat may have given saplings time to occupy sites and maintain dominance over annual weeds well after the applications.

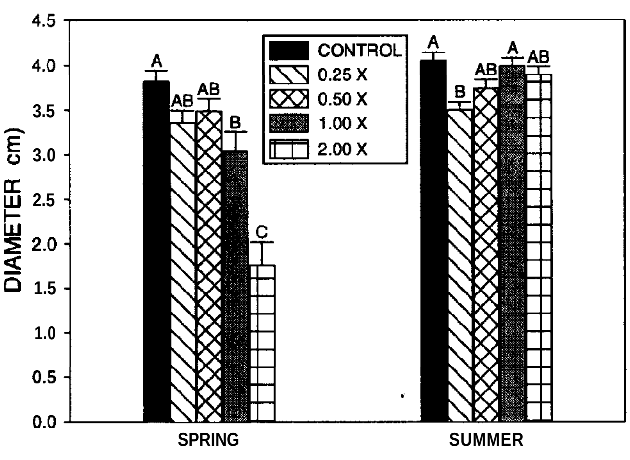

Figure 5—Average stem diameters and standard errors of first-year cottonwood saplings measured in mid-September resulting from application of various doses of paraquat on June 17 (spring), or application of the same doses of paraquat on August 19 (summer). Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different diameters, at P=0.5, tested by Tukey's W Procedure.

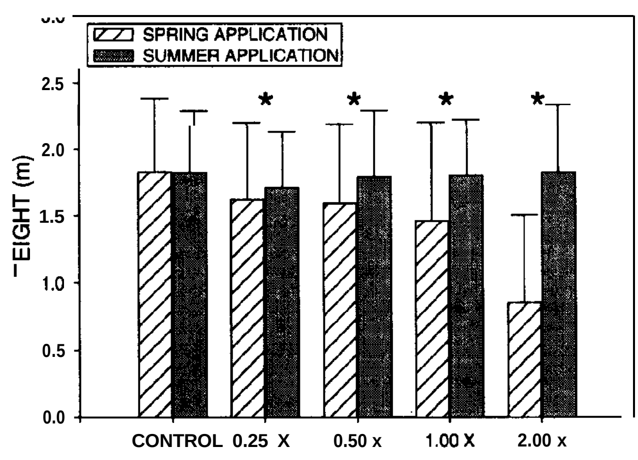

Figure 6-Comparisons between average stem heights, with standard errors, of first-year cottonwood saplings measured in mid-September following either spring or summer applications of various doses of paraquat. Doses are based on a 1.0 rate of 24 ounces per acre. Asterisks indicate different heights between application times, at P=0.5, tested by Tukey's W Procedure.

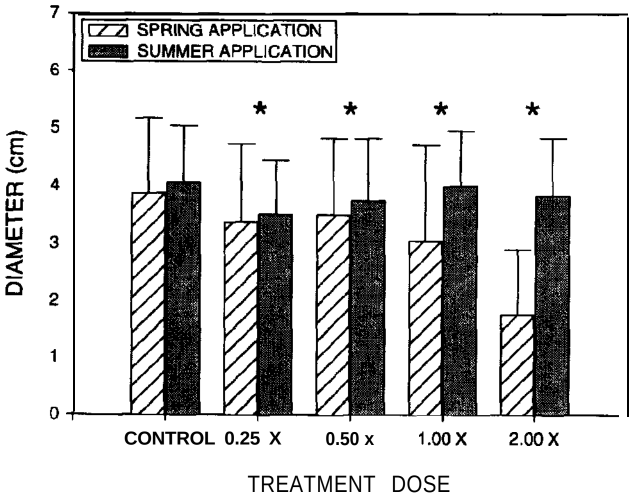

Figure 7-Comparisons between average stem diameters, with standard errors, of first-year cottonwood saplings measured in mid-September following either spring or summer application of various doses of paraquat. Doses are based on a 1.0 rate of 24 ounces per acre. Asterisks indicate different heights between application times, at P=0.5. tested by Tukey's W Procedure.

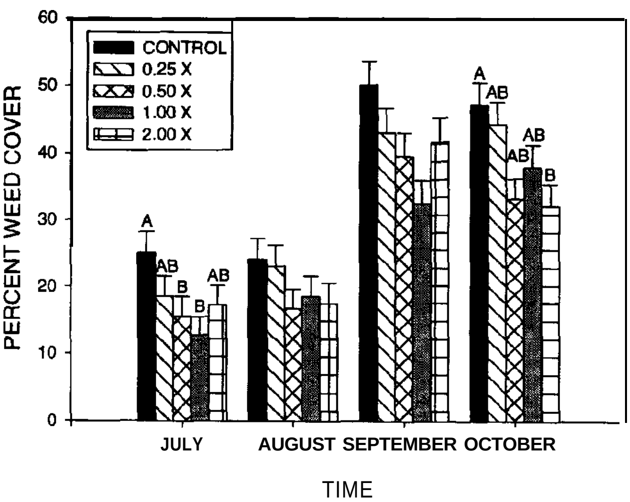

Figure 8-Weed control around the bases of first-year cottonwood saplings, measured by percentage of weed cover (with s.e.m.) within a 0.5 m2 plot, following the application of various doses of paraquat on June 17. Weed cover was assessed at l-month intervals. Doses are based on a 1 .O rate of 24 ounces per acre. Different letters above bars indicate different percentages of weed cover, at P=0.5, tested by Tukey's W Procedure on arc sine-transformed data.

CONCLUSIONS

This study showed that applications of paraquat at 6 oz/ac, the 0.25 x operational rate, caused necrosis of cottonwood bark tissue and stem swellings. Also at this dose, sapling survival was less than for untreated controls, and heights and diameters of saplings treated in June were less than those of saplings treated in August. Higher doses of paraquat increased these effects. Therefore it is inadvisable to apply paraquat around the bases of first-year cottonwood saplings to control weeds before bark tissues have matured enough to be resistant to paraquat damage-probably sometime after mid-summer. Otherwise, sapling mortality or loss of growth is likely to occur. Mechanical cultivation may be all that is needed for weed control since these data do not show any benefit to growth from paraquat applications. Further, a spray rig modified to shield stem bases from the herbicide should be used to apply paraquat. Eastern cottonwood is the fastest-growing commercially important tree species in North America (Cooper and Van Haverbeke 1990), and as such has the innate capacity to recover quickly from injury. Considering the rapid regrowth inherent to the species, cottonwood plantation managers should weigh the advantages of chemical control of annual weeds early in the growing season against the disadvantages of potential decreases in survival and growth in the first year. Additional controlled experiments and documentation of growth beyond the first year could address these issues. These findings should be useful to other commercial, private, and government growers interested in controlling annual weeds in first-year cottonwood plantations, and in reforestation efforts in which cottonwood is planted alone or intermixed with other species.

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COMPARISON OF SOIL BIOASSAY RESPONSES OF LOBLOLLY PINE SEEDLINGS WITH SOIL CHROMATOGRAPHY RESULTS FOR CONVENTIONAL AND CONTROLLED RELEASE HERBICIDES

Craig L. Ramsey, Glenn Wehtje, Harold Walker, Dean Gjerstad, and David South'

Abstract-The duration of herbaceous weed control is dependent on the rate of active ingredient dissipation in the upper soil layers. Controlled release carriers have the potential to maintain the herbicide-soil concentrations at effective "crop safe/weed toxic" levels over extended periods of time. Greenhouse bioassays were used to determine the dose-response of loblolly pine *Pinus taeda L.* and several weed species to a range of hexazinone and sulfometuron soil concentrations. Preliminary results are also reported for the release rates and soil mobility of the commercial, liquid formulation of hexazinone.

INTRODUCTION

The primary factor that determines the duration of herbaceous weed control in pine plantations is the degree of soil activity that can be achieved after a herbicide application. The magnitude of soil activity depends on the inherent properties of the selected herbicide, a host of environmental conditions, and numerous application factors. The soil half-life of a herbicide provides an estimate of the first order dissipation rate of the active ingredients under a specific set of conditions. The half-life of the herbicide-soil concentrations determines the length of time that the active ingredient levels remain within the effective dose range necessary for effective weed control (Cheng 1990).

Forest managers generally seek to achieve both minimal pine seedling injury and optimal weed control when prescribing herbaceous weed control rates. This goal is possible if the soil active herbicide level is maintained between the Toxic Dose (TD_{50}) soil concentration for the crop species and the Effective Dose (ED_{50}) soil concentration needed for most of the weed species (Schreiber and others 1987). Managers usually have to balance the desired level of weed control with the level of pine injury they can tolerate, when they apply single-dose, season-long herbicide applications. Reliance on nature's "regulation" of herbicide-soil concentrations, through first order dissipation, can lead to disappointing results due to erratic or extreme rainfall events, extremes in soil pH or percentage of organic matter, or voracious soil microbes. In addition to maintaining a "crop-safe/weed-toxic" soil concentration range, the spatial movement of the soil-herbicide solution should be restricted, as much as possible, to the upper weed root-zone layer.

Controlled-release herbicide carriers have the potential to both (1) maintain ED,, herbicide-soil concentrations over a season-long time period, and (2) reduce the active ingredient movement out of the weed root zone (Wilkens 1995). The herbicide release rate is controlled by rainfall events and/or surface erosion of the granule. The periodic release of active ingredients somewhat balances the ongoing soil losses to leaching and chemical or biological degradation.

A leaching study with Starch-Encapsulated (SE) atrazine found that 99 percent of the SE formulation was retained in the top 5 centimeters (cm) of the soil column. In contrast, the commercial liquid formulation retained only 18 percent of the active ingredients in the top 5 cm (Fleming and others 1992). Another leaching study with Alginate-Encapsulated (AE) alachlor found that only 4 percent of the AE alachlor was leached from the top 5 cm of soil. The standard liquid treatment, however, leached 33 percent of its active ingredients out of the top 5 cm of the soil column after 420 ml of $CaCL_2$ was leached through the column (Johnson and Pepperman 1996).

The goal of this research project is to improve herbaceous weed control for forest pine plantations through the use of after-market carriers that act as controlled release matrices. The project consists of three separate studies. The first study involves the determination of the TD,, and ED,, herbicide-soil concentrations for loblolly pine seedlings and several weed species. The second phase of the project investigates the active ingredient release rates and soil mobility from several matrices after three leaching events on thin layer soil chromatography plates. The third study is a field evaluation of the effectiveness and duration of weed control and pine safety for several of the controlled release carriers. The results from the greenhouse bioassay study, along with preliminary results from the chromatography study, are presented in this paper.

METHODS

The greenhouse bioassay studies were conducted to determine the dose-response of loblolly pine seedlings and three weed species, broadleaf signalgrass *Brachiaria platyphylla,* sicklepod *Senna obtusifolia,* and tall morning glory *Ipomoea purpurea* to soil applied hexazinone and sulfometuron. The studies were completely randomized with six single container replications of each treatment. The hexazinone and sulfometuron studies consisted of six and five soil concentrations, respectively. Both bioassays were conducted over a 2-month time period. The hexazinone study was conducted twice, the first on August 8, 1996, and the second on October 28, 1996.

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The bioassay soil was collected near Auburn, AL. The soil series is a Uchee loamy sand, classified as a loamy, siliceous, thermic, Arenic Hapludult. The particle sizes were 90 percent sand, 7 percent silt, and 3 percent clay, and the percentage of organic matter was 0.88 percent. The soil had a bulk density of 1.32 grams per cubic centimeter (g/cm^{3}), a pH of 4.8, a field capacity of .11 kilograms per kilogram (kg/kg) and a CEC of 3 cmol. The soil was collected only from the top 20 cm of the soil profile. The soil was air dried, thoroughly mixed, and passed through a 2 millimeter (mm) screen. Planting containers were filled with 1 kg of soil.

The pine soil concentrations for hexazinone were 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0 mg active ingredient (ai) kg-‘. The weed soil concentrations for hexazinone were 0.0, 0.1, 0.15, 0.2, 0.25, 0.3, and 0.35 mg ai kg-‘. The pine soil concentrations for sulfometuron were 0.0, 0.01, 0.05, 0.1, and 0.5, mg ai kg-‘. The weed soil concentrations for sulfometuron were 0.0, 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1.0, 5.0, and 10.0 mg ai kg-’ Each herbicide treatment was diluted in 110 ml of tap water to ensure that the initial soil moisture was at field capacity for each container. Pine seedlings or weed seeds were planted, or sown, as the pre-mixed soil was added to the containers. The loblolly pine seedlings were collected the day before planting from a forest company field nursery. The pine seedlings were 4 months old, with an average weight of 8.6 g for the first study, and 6 months old, with an average weight of 30.1 g for the second study. Each seedling was weighed before planting. Broadleaf signalgrass and sicklepod were sown together in a single container for each herbicide treatment.

Weed control assessments were expressed as percent mortality. Each pine seedling was root washed and weighed on a green weight basis. Differences in fresh weight biomass growth for each soil concentration were calculated by subtracting the initial seedling weights from the final weights. The treatment means for percent weed mortality and pine seedling biomass growth were used to estimate the ED,, and TD,, soil concentration levels for hexazinone and sulfometuron herbicides. These soil concentration estimates will then be used as target goals for the second phase of this project.

The laboratory study involving the kinetic rate of active ingredient release from various matrices combined soil thin-layer chromatography with liquid scintillation techniques. The same soil used for the bioassay study was also used in this study. Controlled release materials, such as crosslinked polyacrylamides, activated charcoal, newspaper fluff, and methylated seed oil will eventually be loaded with radiolabeled hexazinone or sulfometuron using acetone solvent. The preliminary results reported here include only the initial trial for the standard, suspension concentrate formulation of hexazinone, Velpar-L. The liquid formulation trial included three replications of three leaching events, i.e., three plates were leached once, another three plates were leached twice, and the last three plates were leached three times.

Modified plexiglass plates were used to hold the controlled release granules on the soil plates. The soil dimensions on the plates were 90 by 280 mm, with a uniform thickness of 2 mm. Each plate received 60 microliter (l) of radiolabeled hexazinone solution, approximately 2 cm up from the bottom of the soil plate. The hexazinone dose per plate was 1.43 mg of active ingredients. This rate is equivalent to approximately 6.9 pounds (lb) a.i. per acre. The plates were then placed in a water bath with paper wicks to ensure adequate air saturation. The covered baths were individually monitored, and removed as each wetting front reached the 27 cm mark on the plate. Each plate was then oven dried at a low, nonvolatilizing temperature before it was leached again, or set aside for soil counting. After completing each set of leaching cycles, the plates were divided into 27 soil samples, each 1 cm wide. The soil samples were then radio-counted according to the liquid scintillation techniques described by Corbin and Swisher (1986).

RESULTS AND DISCUSSION

The bioassay results for the first hexazinone study involving pine seedling injury are given in figure 1. The horizontal bars in the figure represent the treatment mean, and the vertical bars represent the standard errors. There was a negative, linear reduction in biomass growth for the pine seedlings as the soil concentration increased. Two of the treatment means are labeled with the equivalent active ingredient rate per acre; given that the soil has a bulk density of 1.32 g per cm^3 and the herbicide is uniformly distributed in the top 12 cm of soil.

The two exceptions to this linear trend were the highest hexazinone rates of 0.8 and 1.0 parts per million (ppm). This can be partially explained by the method used to estimate the “growth” for seedling mortality. All of the dead trees were

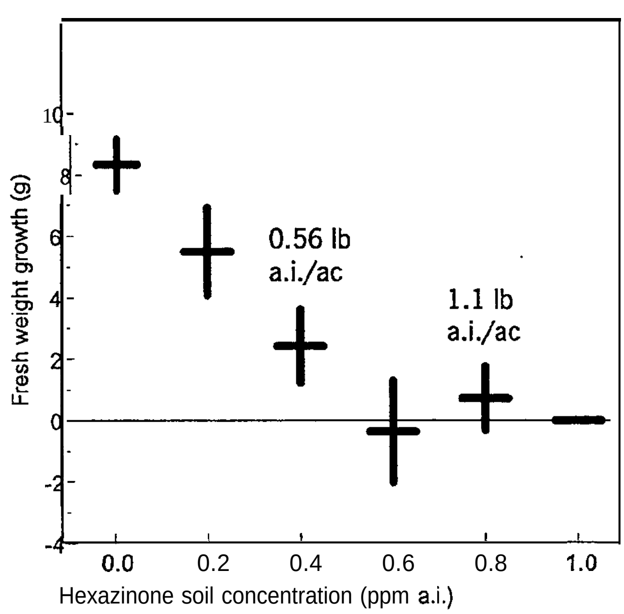

Figure l-Dose-response of loblolly pine seedlings to hexazinone, 2 months after treatment.

assigned a growth rate of zero. All of the seedlings with the 1 .O ppm hexazinone treatment were dead at the end of the 2-month study. Thus, the mean for the 1.0 ppm treatment was zero, with no vertical standard error bar. Pine seedlings may have a negative growth over time if the metabolism rate exceeds the photosynthetic rate, as shown by the 0.8 ppm treatment. Also, both of the standard errors for the 0.6 and 0.8 ppm treatments include zero growth rate.

This trial reveals that any soil concentration of hexazinone above the zero level will reduce pine growth. Approximately 3 g of growth is lost for each 0.2 ppm increment increase in hexazinone soil concentration, over the 2-month period. How much seedling growth loss can be tolerated in order to gain effective weed control is still an open question. The TD,, level for the pine seedlings is between the soil concentrations of 0.6 and 0.8 ppm (w\w). The TD_{100} is 1 .O ppm for the seedlings.

Figure 2 shows the dose-response of germinating signalgrass and tall morning glory to the seven hexazinone treatments, 2 months after treatment (MAT). There is a positive trend between percent weed control and increasing hexazinone soil concentrations. The minimal ED,, for control of these two weed species is between 0.2 and 0.3 ppm (w\w). The ED,,, for these species is between 0.3 and 0.35 ppm.

The margin of soil concentration safety between the TD,, for pine seedlings, 0.6 ppm, and the minimal ED_{50} for effective weed control, 0.3 ppm, is quite narrow. This indicates that the selectivity of hexazinone is restricted for pine seedlings. These results also suggest that hexazinone selectivity is based primarily on spatial patterns in soil concentrations.

Figure 3 shows the dose-response of pine seedlings to five soil concentrations of sulfometuron. There is a general, negative, linear decrease in pine fresh weight growth as sulfometuron soil concentrations increase. Two of the treatment means are labeled with the equivalent active ingredient rate per acre; given that the soil has a bulk density of 1.32 g per cm^3 and the herbicide is uniformly distributed in the top 12 cm of soil. There was no pine mortality over the 2-month period. However, there was an average fresh weight growth loss of 6.6 g per seedling between the soil concentrations of 0.0 and 0.5 ppm, 2 MAT. For every sulfometuron rate increase above 0.01 ppm, there was an average loss of 1.65 g of fresh weight growth. The TD,, cannot be estimated for sulfometuron, given the soil concentration range used in this trial. However, pine growth losses can be minimized by reducing the target herbicide-soil concentrations down to the ED,, or ED,,, weed control soil concentrations.

Figure 4 shows the dose-response of germinating sicklepod to sulfometuron, 2 MAT. There is a positive trend between percent weed control and increasing sulfometuron soil concentrations. The minimal ED,, for control of sicklepod is between 0.005 and 0.05 ppm (w\w). The ED,,, soil concentration is greater than, or equal to, 0.05 ppm.

The results from this trial indicate that sulfometuron is very selective for loblolly pine seedlings. Given the study conditions of uniform herbicide-soil concentrations, and a single germinating summer annual weed, there is a wide

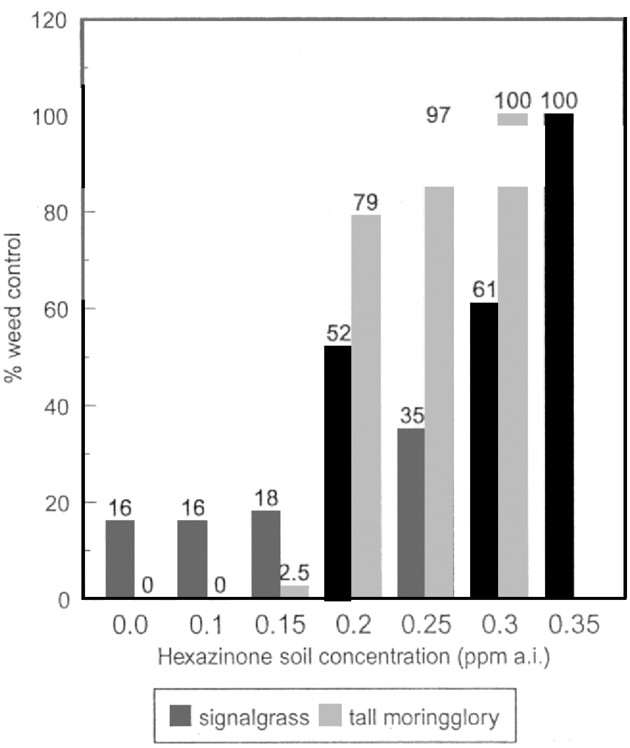

Figure 2-Dose-response of signalgrass and tall morning glory to hexazinone, 2 months after treatment.

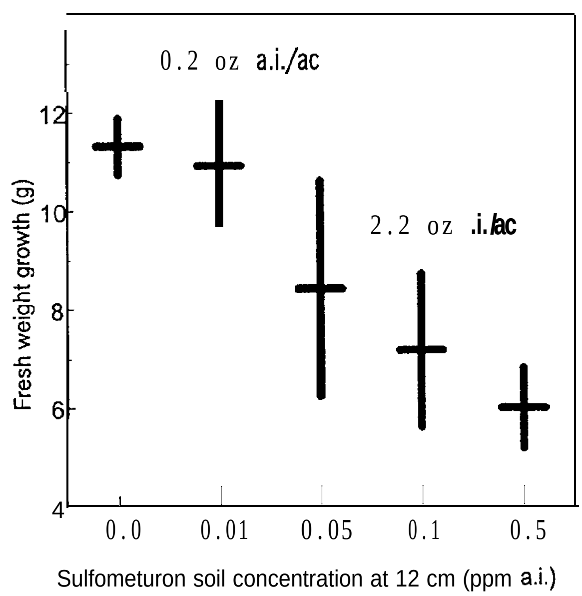

Figure 3-Dose-response of loblolly pine seedlings to sulfometuron, 2 months after treatment.

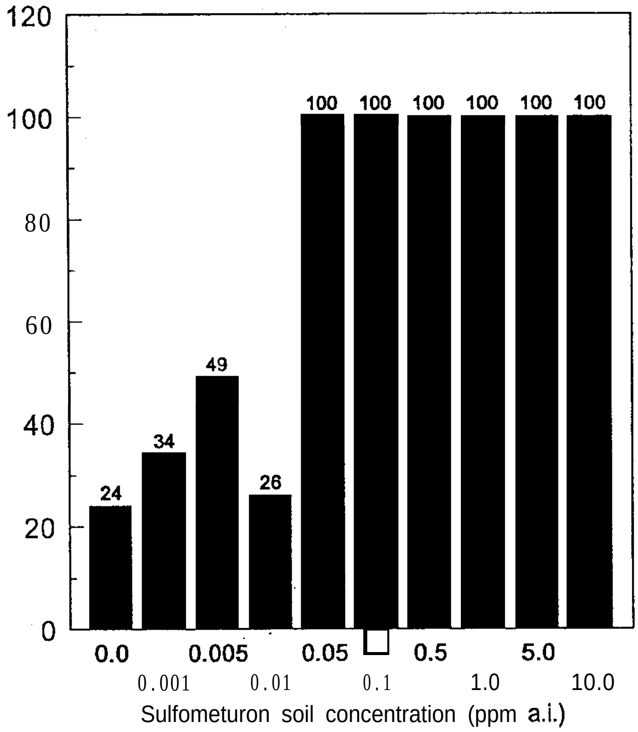

Figure 4-Dose-response of sicklepod to sulfometuron, 2 months after treatment.

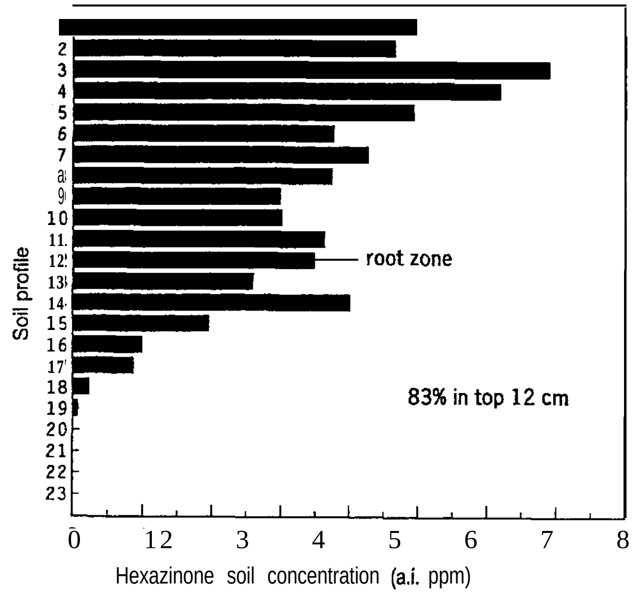

Figure 5—Hexazinone soil concentrations after the first leaching cycle.

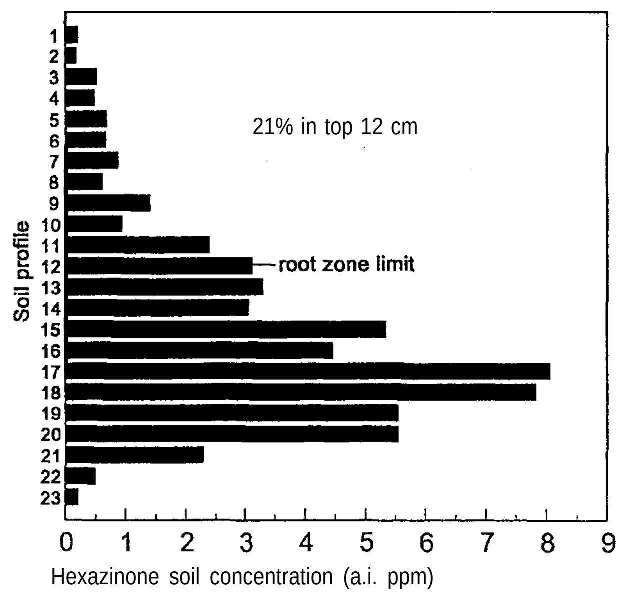

Figure 6-Hexazinone soil concentrations after the third leaching cycle.

margin of safety between the toxic dose level for pines and the effective dose level needed for weed control.

The results from these studies provide the TD,, and ED,, soil concentrations needed to set target release rates for the controlled-release carriers. Caution should be taken when interpreting these results. Soils with high cation exchange capacities, or organic matter content, will require higher dose rates due to high adsorption rates. Hard-to-control weed species will also require higher dose rates. In addition, the spatial patterns in soil concentrations due to active ingredient mass movement need to be taken into consideration, at least for hexazinone applications.

Figure 5 shows the preliminary, nonreplicated results for the first leaching cycle of the liquid formulation of hexazinone. The y axis of the graph is representative of the soil profile. The first bar represents the surface soil concentration, and the last bar represents the soil concentration 18 cm deep in the soil. After the first leaching event, 83 percent of the active ingredients remained in the top 12 cm of soil.

Figure 6 shows the hexazinone leaching results for a thin layer chromotography (TLC) plate receiving three separate bath cycles. Most of the active ingredients had been transported out of the weed root zone. Only 21 percent of the hexazinone remained in the top 12 cm of the soil profile. The soil retained an average of 4.4 ppm in the top 12 cm after the first leaching cycle. The third leaching cycle, however, retained an average of only 1.0 ppm in the top 12 cm of soil. These results show that the hexazinone soil concentration is reduced by 25 percent in the top 12 cm of soil, after three leaching cycles.

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